Case Study

Using global positioning system technology to manage human–black bear incidents at Yosemite National Park

Rachel L. Mazur, Division of Resources Management and Science, Yosemite National Park, 5083 Foresta Road, El Portal, CA 95318, USA *rachel_mazur@nps.gov*

Ryan M. Leahy, Division of Resources Management and Science, Yosemite National Park, 9039 Village Drive, Yosemite, CA 95389, USA

Caitlin J. Lee-Roney, Division of Resources Management and Science, Yosemite National Park, 9039 Village Drive, Yosemite, CA 95389, USA

Kathleen E. Patrick, Division of Resources Management and Science, Yosemite National Park, 9039 Village Drive, Yosemite, CA 95389, USA

Abstract: Managing human–bear (*Ursus* spp.) incidents is a top management priority in national parks inhabited by bears. Yosemite National Park (Yosemite), located in the Sierra Nevada in California, USA, receives up to 5 million visitors annually. It is also home to 300–500 black bears (*U. americanus*). Yosemite has an extensive history of black bear research, educational programs, and innovative solutions for reducing human–bear incidents. Despite this, human–bear incidents peaked in 1998 at 1,584. The resulting political fallout led to Yosemite receiving funds to expand its bear management program, including increasing its staffing and garbage pick-up, and improving the park's bear-resistant infrastructure. In 2011, Yosemite reached a milestone when it recorded only 114 human–bear incidents—a 93% decrease from the 1998 high. To sustain this lower level of incidents while facing shrinking budgets and increasing visitation, bear managers turned to more modern technology. From 2014–2018, we evaluated the effectiveness of using global positioning system (GPS) collars to manage bears more proactively, increase staff and public engagement with bears, and gain insight into the bears' spatial and temporal movements. The GPS collars were effective in achieving these goals, while also improving both our time management and our communication with park management. By the end of November 2018, Yosemite had recorded only 22 human–bear incidents—a 99% decrease from the 1998 high. The GPS collars are now an integral part of the Yosemite bear management program. We provide recommendations on how GPS technology may help other parks reduce human–bear incidents.

Key words: black bear, global positioning system, *Ursus americanus*, wildlife management, Yosemite National Park

In the United States, the National Park Service (NPS) was created to "…preserve unimpaired the natural and cultural resources of the national park system…" That system now includes 60 national parks that encompass >30 million hectares of public lands. Collectively, in 2018, national parks received >330 million visitors (NPS 2017*b*). Nearly a third of national parks provide habitat for bears (*Ursus* spp.; NPS 2018). Bear species include the polar bear (*U. maritimus*), the brown/grizzly bear (*U. arctos*), and the black bear (*U. americanus*). As such, managing human–bear incidents is a top management priority in national parks inhabited by bears.

American black bears found in Yosemite National Park (Yosemite), located in northern California, USA., have long been of interest to park visitors and managers. Seeing one of the estimated 300–500 black bears that inhabit Yosemite can evoke excitement, awe, and fear (Lackey 2003). In 2011, Yosemite's human–black bear management program reached a milestone when it recorded only 114 human–bear incidents—a 93% decrease from its high of 1,584 incidents in 1998 (NPS, unpublished data). Yosemite defines an incident as "a bluff charge or other aggressive behavior, personal injury or contact, property damage (including damage to food), bear trapped/released from

Figure 1. Yosemite National Park, California, USA, covers 3,080 km² on the western slope of the Sierra Nevada in California.

dumpsters, or a bear entering a building" (NPS 2002*a*).

This remarkable success did not come easily. It was the result of almost 100 years of trial and error, clever inventions for trapping bears and storing food and garbage, targeted research, increased funding, and innovative signage and education (Mazur 2014). It was also the result of a large and dedicated staff; by then Yosemite had a staff of 12 employees and volunteers dedicated to the bear program each summer. The substantial decrease in incidents was tenuous, however; as budgets were decreasing, visitation was increasing, and park employees were working themselves to exhaustion. To sustain this decreased level of incidents, Yosemite had to increase its capacity without increasing employee workload.

In 2003, researchers working in Yosemite created a bear monitoring system that tracked bears through very-high frequency (VHF) signals installed on collars (Breck et al. 2007). In areas of continual incidents, bear management staff set up monitoring boxes designed to send a message over the park's 2-way radio system whenever the boxes detected a radio-marked bear's VHF signal. Prior to employing this new system, bear management staff were reactive to incidents that already occurred; however,

with the new system, staff could prevent incidents from occurring by hazing bears out of developed areas as soon as they detected bears entering them. The monitoring boxes were also an effective outreach tool, as visitors were fascinated with the boxes and enjoyed looking at the resulting graphs of activity patterns. With the success of the monitoring boxes, it was logical to look for additional technologies that could increase capacity farther.

From 2014–2018, we evaluated the effectiveness of using global positioning system (GPS) collars, rather than VHF collars, to help manage human–bear incidents more effectively. Specifically, we wanted to determine if the GPS collars increased our capacity to manage bears proactively, improved the effectiveness of our management actions, increased staff and public engagement with bears, and provided us with better information about the spatial and temporal movements of the bears.

Management area

Yosemite National Park covers 3,080 km² on the western slope of the Sierra Nevada in California (Figure 1). It ranges in elevation from 648 m in the low western foothills to 3,997 m on the crest of the Sierra Nevada and is composed largely of steep topography and large expanses of inaccessible areas. Vegetation types include chaparral, oak (*Quercus* spp.) woodland and savannah, upland hardwood forest, conifer forest, woodland, meadows, and alpine plant communities.

The region's Mediterranean climate is characterized by wet snowy winters and long dry summers (Stephenson 1988). Up to 5 million visitors come to Yosemite each year (NPS 2017*b*), with the bulk of visitation concentrated in the 18-km² area of Yosemite Valley. Developed areas include 13 campgrounds with almost 2,000 campsites, 7 lodging facilities, and 5 developed picnic areas.

Methods
GPS collars

In Yosemite National Park, between 2014 and 2018, we fitted up to 14 adult black bears each year with GPS collars. We targeted bears we previously documented to be in conflicts with humans, obtained human food or garbage, or frequented developed areas. The GPS collars

Figure 2. Managers at Yosemite National Park, California, USA fitting yearling bears (*Ursus americanus*) with global position system collars at Lake Tahoe Wildlife Care, Inc. in January 2017 (*photo courtesy of D. Wharton*).

contained both GPS and VHF functionality.

To capture bears, we used metal culvert traps or dart guns (Daninject, Wildlife Pharmaceuticals, Fort Collins, Colorado, USA). We immobilized bears using Telazol (4.2 mg/kg, Fort Dodge Laboratories, Fort Dodge, Iowa, USA), and fitted each one with a GPS collar that weighed 1.4 kg (Vertex Plus, Vectronic, Berlin, Germany). The GPS collars were programmed to record the bear's location every hour and to transmit the resulting data every fourth hour. We programmed a breakaway mechanism on each GPS collar to release 2 years from deployment.

We marked each bear's ear with colored and uniquely numbered rototags (Allflex International, Dallas, Texas, USA), installed a microchip (HomeAgain, Merck, Kenilworth, New Jersey, USA), and recorded morphological measurements. All captures fell within the purview of the Yosemite bear management program, including the Yosemite Human–Bear Management Plan (NPS 2002*a*), the Yosemite National Park Capture Manual (NPS 2002*b*), and the Protocol for Use of Anesthesia for Black Bear Capture and Handling (NPS 2017*a*).

In 2017, we also deployed GPS collars on 3 yearling bears. We had sent these siblings to the Lake Tahoe Wildlife Care, Inc. rehabilitation center, Lake Tahoe, California, USA, when they were cubs the previous year (July 2016), after a vehicle struck and killed their mother (Figure 2). Upon their return to the park in January 2017, we fitted the yearlings with GPS collars prior to denning them so we could follow their movements and determine whether the

reintroduction was successful. We programmed their GPS collars to record their location every 30 minutes, to transmit the data hourly, and to drop off 6 months after their deployment.

Website and blog

We developed a website, KeepBearsWild.org, to engage the public by sharing both the bears' GPS movement data and the lessons learned from the bears' movements. The Yosemite Conservancy (YC), our nonprofit partner, sponsored the site and hired a programmer to keep it current, while the NPS provided the data and content. While not currently on the NPS site, the KeepBearsWild.org site used software compatible with the NPS system so we could move KeepBearsWild.org to the NPS site in the future. We designed the website to engage the public with interactive graphics of bear movements and then educate them with information on bear ecology and how to live responsibly with bears.

KeepBearsWild.org displayed the bears' GPS data to the public through an interactive mapping application called Bear Tracker. The movement data was displayed as tracks that were offset by several weeks to protect bears from potential harassment. Tracks leading to den sites or from bears that had left the park were not displayed. The Bear Tracker also showed the locations where bears had been hit by cars, as well as the disposition of each bear after it was hit.

We shared more in-depth information through a blog on KeepBearsWild.org. Roughly once a month while the bears were active, a bear team member wrote a blog based on what we had learned from the GPS data and how we were applying what we had learned to improving our management. Each blog included a conservation message. KeepBearsWild.org also included information about food storage, the Yosemite bear management program, and how to reduce vehicle–bear collisions.

Outcome and discussion
GPS functionality

Each year from 2014 through 2018, we deployed GPS collars to maintain a sample size of 3–7 male bears and 6–7 female bears. The GPS collars obtained fixes roughly 50% of the time within Yosemite Valley and roughly

75% outside the Valley. The most problematic areas were at the base of the steep canyon walls around the edges of the Yosemite Valley. When the GPS collars did obtain fixes, they were generally accurate to well within 5 m.

Proactive bear management

Prior to using GPS collars, proactive management included educating the public about bears and providing bear-resistant food storage facilities. Hazing fell into the category of reactive management because it was almost always implemented after a bear obtained human food or garbage (Hopkins et al. 2010). At that time, the only way bear managers knew if a bear was approaching a developed area was to track its VHF signal, and since they were tracking up to a dozen bears over an enormous area, they rarely intercepted bears before they obtained food or garbage. The exceptions were when bear managers either knew a bear's pattern and planned to intercept it, or when bear managers staked out problem areas (Mazur 2010). With the monitoring boxes, bear managers could attend to other work and only try to intercept bears or stake out problem areas when they knew bears had entered the area. It was faster and more effective but still reactive because the bears were already at the developed area.

With the GPS collars, bear managers could be proactive with hazing because the data indicated when a bear was in the vicinity of a problem area. In a single case, a bear fed from an open kitchen on private property near the south end of the park in 2017. The owner requested help from Yosemite staff, and since his property was on land surrounded by the park, bear managers responded. They caught the bear on park land, collared the bear, and aggressively hazed it for 2 days.

Then, the bear managers left the area but continued to monitor the bear's location remotely. When GPS data indicated the bear was approaching the property, bear managers contacted the property owner to ensure the kitchen was bear-proof. They would then head over to haze the bear. After 2 weeks, the bear stopped approaching the camp. However, the GPS data also showed the same bear found other unsecured structures outside Yosemite and continued to obtain anthropogenic food

until it denned for the winter. Even the level of proactive hazing bear managers could do with these GPS collars was not enough because the bear received a food reward before being collared. Truly proactive hazing must occur before a bear obtains any food reward. Ideally, bear managers would fit bears in the vicinity of developments with GPS collars before the bears received a food reward.

Management effectiveness

There were several ways we used GPS collars to test the effectiveness of Yosemite's bear management, including determining if improvements in garbage management were making a difference. Matthews et al. (2006) showed that replacing or repairing bear-resistant facilities reduced or eliminated incidents; however, we did not know exactly how bears reacted to these changes. With the GPS collars, we learned that within a day (<24 hours) of replacing bear-resistant containers in the Valley, bears that had remained continuously in the area for the past week finally left the area, returning only once a day to check the trash lids and then finally leaving the area completely after not getting another reward.

We also used the GPS collars to determine how we could better address backcountry incidents. In Yosemite, backpackers are required to carry bear-resistant portable canisters to prevent bears from obtaining food or garbage (Martin and McCurdy 2009). In 2014, a bear or bears that frequented a single campsite on a cliff above the Valley learned to roll canisters over the edge of the cliff to break them open. The bear would then retrieve the contents of the broken canisters. Had this behavior occurred in multiple locations or by multiple bears, Yosemite would have had to find a new food storage solution. Our GPS data showed that all incidents were from a single bear, and that this bear only frequented that particular camping area. We were able to stop these site-specific incidents simply by closing the area to camping. This management action not only kept this bear from obtaining more anthropogenic foods in this location, but it may have prevented her from passing on the behavior to her cubs (Mazur and Seher 2008).

A third way we used the GPS collars to test

Figure 3. A "Red Bear Dead Bear" sign at Yosemite National Park, California, USA, set up at the location of a vehicle–bear (*Ursus americanus*) collision (*photo courtesy of D. Wharton*).

results of our management actions was to evaluate the success of our efforts to rehabilitate 3 yearling bears that were orphaned as cubs. As previously described, we sent these bears to a rehabilitation center as cubs in 2016 after a vehicle struck and killed their mother. Upon their return to the park in January 2017, we fitted the yearlings with GPS collars prior to denning them so we could evaluate the success of the effort. Although we had rehabilitated cubs and then released them as yearlings in the past, we had relied on VHF collars to monitor post-release movements, and this was limited in scope (NPS, unpublished data).

The GPS collars confirmed that the 3 yearlings dispersed separately. One male apparently died from natural causes, as he was far from roads when we found him partly decomposed. A second male also died; he entered campgrounds early on and became habituated and food-conditioned. Although park personnel put an enormous amount of effort into mitigating the problem, the bear continued to cross roads to visit developed areas. At the end of 2017, his fate mirrored that of his mother when a vehicle struck and killed him. The third yearling, a female, stayed wild and survived the full first season after release.

Public engagement

KeepBearsWild.org went live on April 1, 2017. From its launch through August 31, 2018, the site received 198,921 page views by 93,520 users (D. Wharton, Wharton Media, personal communication).

The Bear Tracker is the central feature of the site. The early feedback from the public was overwhelmingly positive, but the public expressed concern that by displaying bears' tracks, we were encouraging visitors to find and disturb bears, even with the offset. Although we disagreed because of all the precautions already taken to prevent this, we changed the display to show home range polygons.

The website also features the Bear Team Blog. The first blog featured a single bear's movements and the numerous times that bear crossed park roads. With vehicle–bear collisions regularly exceeding 25 per year, this was an area of great concern. The blog provided an educational message to readers including suggestions to drive the speed limit and remain alert for animals on the roadway. That format was standard for the blog; each one incorporated the movements of a bear or bears to engage the reader, then linked the movements to a conservation or management issue, and closed by giving the reader ways to help. As of the end of November 2018, the bear team had written 9 blogs.

Some blogs were stories teaching readers why we no longer relocate bears, the importance of storing food, or why it is important to stay at least 50 m away from bears. Other stories were part of a series, with the idea that the reader will return to the site to learn more. In 2018, we featured a 3-part series about the cubs that went to rehabilitation and what happened to them when they returned. The story invited the reader to connect with the cubs, learn about the enormous amount of effort required, and shared our frustration in the outcome.

The Bear Tracker and the blog drew readers to site, but once there, visitors learned about bear biology, bear management, food storage, and safety around bears. They also learned about another Yosemite innovation: the "Red Bear Dead Bear" initiative. This initiative began in 2007 to raise awareness about the frequency of vehicle–bear collisions (>400 since 1995 and the leading cause of bear deaths in the park; NPS, unpublished data). Yosemite also placed attention-grabbing red and yellow signs anywhere a collision occurred in the park during a calendar year (Figure 3).

A major oversight of the program was that we assumed drivers seeing the signs knew what they meant. Although explanatory signs were placed in the visitor centers, the website
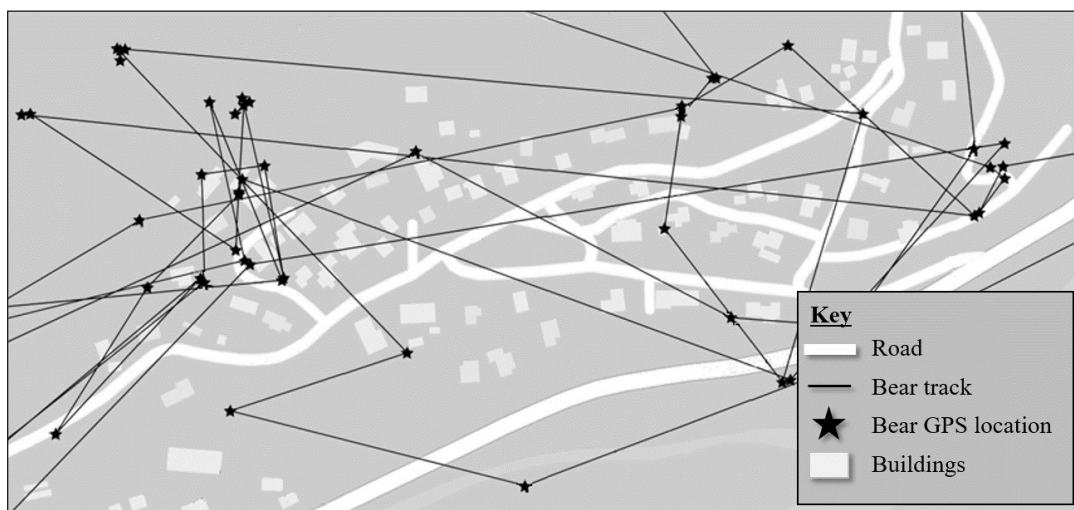
Figure 4. The movements of a black bear (*Ursus americanus*) fitted with a global positioning system collar in the Yosemite National Park gateway community of El Portal, California, USA.

provided yet another way to explain the significance of the signs to visitors.

The Yosemite human–bear management program, long a favorite topic of the media, has garnered even more attention with the advent of the GPS collars. Recent coverage included radio (e.g., *NPR All Things Considered*, *NPR Yosemite Land Podcast*), newspapers (e.g., *Mariposa Gazette*, *San Francisco Chronicle*), magazines (e.g., *Outside Magazine*, *Boys Life*, *Hemisphere*), and television (e.g., *NBC Today*, *NBC OpenRoad*). These stories, like the website, include information on the GPS data, what we are learning from those data, and other information about the bears and how to keep them wild.

Another way we used the GPS data for outreach was in the distribution of paper maps showing the bears' movements through local towns. Park residents and neighbors were more willing to pick fruit or bear-proof their yards after they saw GPS tracks from bears visiting their yards each night (Figure 4). They were also more willing to consider that some bears are active all winter and that their efforts had to be year-round.

Research

Although not our primary goal, we used the GPS data to learn more about the bears' temporal and spatial use of the park. We now have 5 years of data on both male and female adult bears. These data are being used to learn more about where they cross roads, when they move in and out of the park, and how their ranges overlap with human-use areas.

Based on our initial review of the data, we are pursuing questions to learn how bears sample their habitat. Based on prior research using GPS collars on adult females in Sequoia National Park (Mazur et al. 2013), we know there are times when bears detect a new food source when it becomes available, likely by smell, and immediately head out of their current range to feed on it. The Yosemite GPS data suggest that some bears are doing that as well, but others are spending time sampling their habitat. We have tracks of males and females without cubs traveling in loops multiple times until a new food source is available, and then stopping to feed on it.

In 2018, a Yosemite bear stopped what it was doing when the Ferguson fire began and traveled directly into the footprint of the fire. It foraged there for several weeks, even sleeping there, and then left just as quickly and directly (Figure 5). We suspected the bear was feeding on beetles from the genus *Melanophila*, also known as charcoal beetles, known for sensing infrared heat and laying their eggs at the edge of the fire.

Unexpected benefits of GPS

In addition to the results discussed above, we realized 2 unexpected benefits. One was in convincing park management to take action. We have long known visual messages are helpful to managers, such as taking photographs
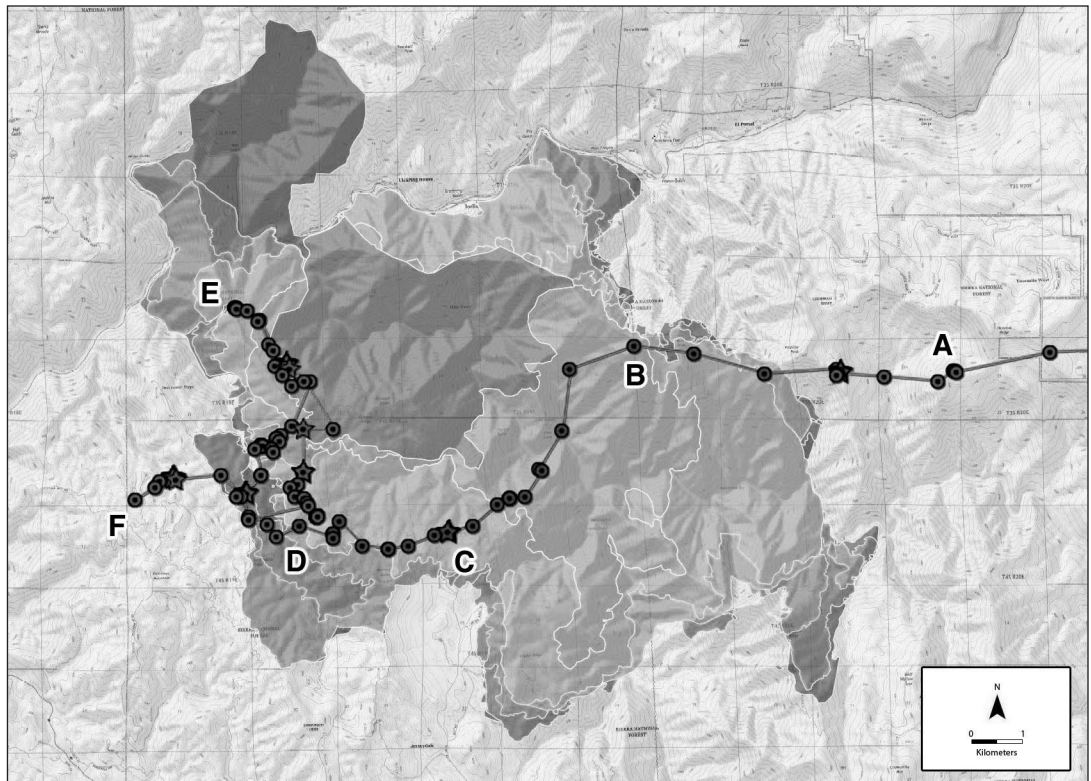
Figure 5. The locations of a black bear (*Ursus americanus*) fitted with a global positioning system collar as it entered the perimeter of the Ferguson Fire on July 15, 2018 (A to B), spent 4 days within the fire footprint (B-E), and then left (E to F), Yosemite National Park, California, USA.

of dumpsters that were over-filled during a weekend and showing them to managers who only work during the week (Mazur 2014). As it turned out, showing the bears' tracks to managers was even more effective. One example was in getting a temporary, targeted speed reduction. During a mast year for Huckleberry oak (*Q. vacciniifolia*) acorns along the Tioga Road, we became concerned about the number of bears crossing the road numerous times each day to forage on them. We showed the Yosemite management team maps of the GPS movement data to emphasize the extent to which the bears were using of the area and the managers approved the temporary speed reduction that day.

A second example was in convincing management we needed to pick all the apples from the historic Curry Orchard before allowing visitors back in after the fire by showing management maps of some of the bears' nearly continuous presence in the orchard when apples are present. The orchards are historically significant but are a source of incidents as they

draw bears right into a busy parking lot if not picked promptly (Greenleaf et al. 2009).

The other unexpected benefit of the GPS collars was the improvement in time management for the bear management staff. Every day, the bear management staff has a myriad of tasks to attend to, including patrolling developed areas to check on proper food and garbage storage, education, and responding to bear-jams and other wildlife incidents. In addition, they need to be as proactive as possible with known, collared bears. Prior to having GPS collars, they were constantly checking for those bears using radio-telemetry and staying on well after they hazed the last one out of a developed area. With the GPS collars, they can check on the bears' locations prior to their shift and know where to focus their time.

Conclusions

Human–bear incidents have occurred in Yosemite for >100 years. Even after Yosemite created one of the most comprehensive bear management programs in the NPS, incidents

peaked in 1998 at 1,584. Media attention from that peak, however, led to the park getting the funds it needed to finish bear-proofing and increasing staffing, and by 2011, incidents were down by 93%. In 2014, the bear team added GPS technology to its toolkit to attempt to increase its capacity to maintain that new low, as inflation was decreasing the value of the funding acquired in 1998 and visitation was increasing. By the end of November 2018, Yosemite had only 22 human–bear incidents, the lowest ever recorded and a 99% decrease from Yosemite's high in 1998.

The addition of GPS collars to the Yosemite human–bear management program was a contributor to this success. The GPS collars enhanced our proactive management, gave a boost to our public outreach and education, and provided a wealth of research potential. They also allowed us to communicate more clearly with managers and greatly improved our time management.

One of the questions we had about the GPS collars was if they would work in the steep-walled Yosemite Valley. Although the GPS collars worked much better than we expected, there were days when we only received a few fixes on some of the bears. We achieved our goal, but only because we used the GPS collars as a complement to the VHF, rather than as a substitute. With a single fix, we still have a good idea if a bear is nearby, even if we do not know exactly where it is, because we can then find the bears using the VHF.

There are downsides to using the GPS collars. First, they cost $3,000–$5,000 compared to the cost of VHF collars at roughly $600. Another limitation is that there is more set-up time than with VHF collars. That includes programming the GPS collars and setting up technological interfaces to interact with the data. Finally, it is critical to keep the bear management staff focused not only on these data that are coming from the collared bears, but also engaged in the day-to-day work of protecting naïve bears by checking hotspots and in working to make the park bear-proof.

There were similar pros and cons to the KeepBearsWild.org website. It has been highly successful and will likely only get more popular, but funding and required maintenance time may prove prohibitive.

Management implications

A successful human–bear management program must start by providing a full complement of bear-resistant facilities. After that, education is critical, for only motivated people will use those facilities. At that point, a strong program can go a step further by adding GPS technology to its repertoire. At Yosemite, that addition took the program further while resources shrunk and visitation increased. Due to this successful pilot, both the GPS collars and the KeepBearsWild.org website are now integral parts of Yosemite human–bear management. We recommend adding GPS technology to bear programs currently using VHF collars where bear-proofing is complete and there is a need to increase capacity, regardless of whether the collars will be used for research. The start-up time and funds will be minimal compared to the savings in time and funds needed in managing future incidents.

Acknowledgments

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RACHEL L. MAZUR holds M.S., M.P.A, and Ph.D. degrees. She began her career at Zion National Park in 1989, circled through several national parks and a national forest, detoured into the private and nonprofit sectors, and landed in Yosemite in 2014. Outside of work, she is the author of several children's books and a history of bears in the Sierra, titled *Speaking of Bears*. She is currently the chief of wildlife at Yosemite.

RYAN M. LEAHY graduated from Allegheny College with a B.S. degree in biology. He began his career with the National Park Service in the Great Smoky Mountains and later honed his field skills at Sequoia and Kings Canyon. He is now a wildlife biologist at Yosemite National Park, where he is exploring how innovative technologies can expand the effectiveness of Yosemite's human–wildlife management program.

CAITLIN J. LEE-RONEY graduated from the University of California–Santa Cruz with a B.S. degree in ecology and evolution and a B.A. degree in environmental studies. She began working with Yosemite bears in 1999 as a volunteer, then a seasonal employee, and finally a permanent employee in 2007. Since 2011, she has been the wildlife biologist in charge of Yosemite's human–bear management program.

KATHLEEN E. PATRICK has a bachelor's degree in wildlife biology from Humboldt State University. She began her career in wildlife in 2007 by working seasonally with Yosemite bears, then with California condors at Pinnacles National Park, and finally with bats through Colorado Parks and Wildlife. She returned to Yosemite in 2012 to be the permanent field lead for the human–bear management program.